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Effects of meteorological factors and the lunar cycle on onset of parturition in cows

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INHALT

ABSTRACT

The present paper summarizes a comprehensive retrospective study that was undertaken to investigate effects of meteorological factors and lunar cycle on gestation length and birth rate in cows. To this end, all cattle births in Switzerland between 2008 and 2010 (n=2,091,159) were related to detailed interconnected weather recordings. The study shows that neither birth rate nor gestational period had a clear association with temperature, barometric pressure or relative humidity. Only thunderstorm activity and a high heat index in the days preceding parturition had a statistically significant effect on gestation length, however, the practical relevance for the reduction by 0.4 and 0.01 days, respectively, seem negligible. As expected, also no influence by the moon was found since births were distributed unevenly across the lunar cycle without clear pattern.

Keywords: cattle, parturition, birth, weather, moon

ZUSAMMENFASSUNG

Die vorliegende Arbeit untersucht in einer retrospektiven Studie den Einfluss spezifischer meteorologischer Faktoren sowie des Mondzyklus auf die Trächtigkeitsdauer und die Geburtenrate beim Rind. Dazu wurden alle Rindergeburten in der Schweiz über den Zeitraum von 2008 bis 2010 (n=2‘091‘159) analysiert indem sie mit detaillierten, lokalen Wetterdaten zum Zeitpunkt der Geburt vernetzt wurden. Die Studie zeigt, dass weder die Geburtenrate noch die Trächtigkeitsdauer einen klaren Zusammenhang mit Temperatur, Luftdruck, oder Luftfeuchtigkeit aufweisen. Einzig lokale Gewitter sowie ein hoher Hitzeindex an den Tagen vor der Geburt zeigten einen statistisch signifikanten Effekt auf die Trächtigkeitsdauer. Allerdings scheint eine Reduktion der Trächtigkeitsdauer von 0.4 bzw. 0.01 Tagen kaum von praktischer Relevanz. Wie erwartet geht aus diese Studie weiter hervor, dass der Mondzyklus keinen Einfluss auf die Geburtenrate hat, zumal die Geburten eine unregelmässige und zufällige Verteilung aufweisen.

Schlüsselwörter: Rind, Geburt Wetter, Mond

1 INTRODUCTION

The parturition in cows is a complex and multifactorial process and many facets remain unknown despite extensive research efforts in this field. Maternal and fetal endocrine functions surrounding parturition have been largely clarified; maturation of the fetal hypothalamo-hypophyseal-adrenal axis leads to secretion of fetal cortisol, which in turn causes increased estrogen production in the feto-placental unit. This increase results in maternal secretion of prostaglandin $F2_{\alpha}$ ($PGF2_{\alpha}$) causing luteolysis and myometrial contractions, culminating in the birth of the calf [1].

There are several endogenous and exogenous factors that are associated with onset of parturition and gestation length. The former include breed, fetal sex and birth weight. Mean gestation length can differ by up to 9.5 days among cattle breeds with Jerseys having the shortest and Blonde d'Aquitaine the longest gestation [2]. In the same study, the gestation length of heifer calves was 1.78 days shorter than that of bull calves. The latter phenomenon may be explained by a positive correlation between birth weight and gestation length [3,4] because newborn heifer calves weighed up to 5% less than bull calves [2].

Exogenous factors include the season; calves born in the spring have a longer gestation length than calves born in the other seasons [2,5]. Barometric conditions and the lunar cycle are other exogenous factors related to onset of parturition that are frequent topics of controversial debates, but relevant scientific veterinary studies are rare [6,7]. A study spanning several years and involving several hundred beef cows showed that parturition followed a mean decline in barometric pressure [7]. On the other hand, a prolonged period of stable barometric conditions led to a reduction in gestation length of up to 5 days in cows of the Austrian Braunvieh breed [6]. There have been two studies in people that showed associations between clustering of births and pronounced barometric pressure changes or low barometric pressure [8,9], but similar associations did not occur in other studies [10,11]. The effect of the lunar cycle on onset of parturition is even more controversial and, to our knowledge, there have been no veterinary studies on this topic. Studies of the lunar cycle and parturition in people have produced ambiguous results; most authors found no correlation between lunar phase and number of births [10,12–14] while one found a trend [15] and others a significant association between lunar phase and onset of labor [16].

The goal of this study was to investigate associations between multiple weather variables and lunar cycle and onset of parturition in cows. Since local variables such as herd management and local climatic conditions are known to have an effect, the present study includes the entire cattle population of Switzerland over a 3 year period. Furthermore data was analyzed in two ways: First the effect of the weather preceding the individual birth on the gestation length and second if and how weather and the lunar cycle affect the daily birth rate. In accordance with former studies, our calculations concentrate on weather changes such as fluctuations in barometric pressure, air temperature, relative humidity and on exceptional circumstances like thunderstorms, and a high heat index that is known to largely influence the human or animal organism [17,18].

2 MATERIALS AND METHODS

2.1 Animals

By law, all cattle in Switzerland have to be registered in a central database (http://www.tierverkehr.ch/). For the present study, data from all cattle born between January 1, 2008 and December 31, 2010 were extracted (n=2,157,055). The data set contains breed, date of birth, farm registration number and postal code of the birthplace. Date of conception is available for cattle registered in a breed association. Only those breeds and cross breeds that had at least 1,000 births during the study period were included. The following criteria were enforced to ensure correctness of the extracted data: gestation length of 260 to 330 days, age of dam of 15 months to 26 years and birth weight of 10 to 100 kg. Incomplete data sets were eliminated, which left 2,091,159 births for analysis.

To minimize selection bias due to breed occurrence or seasonal clustering of births, the gestation length (GL) and the birth rate (BR = number of births per day) were standardized [2].

To account for breed specific gestation length the residual of gestation length was computed by taking the difference between breed average of the available dataset and the individual gestation length (residual of gestation length, RGL).

The seasonal variations of the birth rate due to grazing seasons in the Alps were accounted for by using a moving average birth rate at day *i* ($\widehat{BR_i}$) over a windows of ± 15 days (N_F=15):

$$\widehat{BR_i} = \frac{1}{2N_F + 1} \sum_{j=i-N_F}^{i+N_F} BR_j . \tag{1}$$

Finally, this running mean birth rate was subtracted from the observed birth rate to obtain the seasonally filtered variation of the birth rate, referred as season independent birth rate (SIBR):

$$SIBR_i = BR_i - \widehat{BR_i} + \frac{1}{N} \sum_{j=1}^{N} \widehat{BR_j} . \tag{2}$$

2.2 Meteorological data

Meteorological data were retrieved from the Swiss federal meteorological database, MeteoSchweiz (IDAweb: http://www.meteoschweiz.admin.ch/web/de/services/datenportal/idaweb.html). Daily recorded variables from 336 Swiss weather stations were used in this study (Fig. 1A). The following variables were selected because they are main determinants of weather and have the potential to affect the wellbeing of people and animals [17]: Maximum, minimum and mean barometric pressure corrected for sea level (p, hPa), air temperature (T, °C) and relative humidity (φ, %); the latter two were measured 2 m above ground level. Days with thunderstorms in a 3 km radius of the birthplace were also considered because thunderstorms are known stress factors [18].

The heat index (HI) was computed according to Rothfusz [19] based on maximum and mean daily temperatures and relative humidity:

$$\begin{aligned} &HI = c_1 + c_2 T + c_3 \varphi + c_4 T\varphi + c_5 T^2 + c_6 \varphi^2 + c_7 T^2 \varphi + c_8 T \varphi^2 + c_9 T^2 \varphi^2 \\ &c_{1..9} = \left[\text{-8.79; 1.61; 2.34; -0.15; -1.23} \cdot 10^{-2}\text{; -1.64} \cdot 10^{-2}\text{; 2.21} \cdot 10^{-3}\text{; 7.26} \cdot 10^{-4}\text{; -3.58} \cdot 10^{-6} \right] \end{aligned} \tag{3}$$

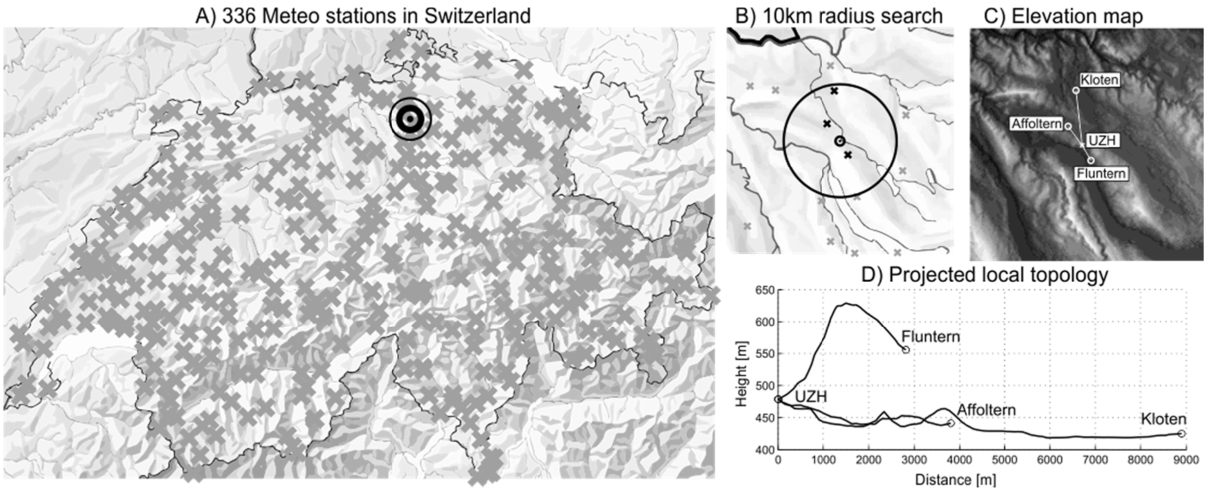

Fig 1. Linking weather to individual birth. (A) Map of Switzerland showing the location of all weather stations (grey crosses). (B, C, D) Identification of the weather station best suited for a particular birthplace (UZH): (B) Weather station must be within a 10-km radius of the birthplace (UZH). (C) Air lines between place of birth (UHZ) and 3 weather stations on grayscale terrain map based on Swisstopo digital height model with a 200-m grid (**http://www.toposhop.admin.ch/de/shop/products/height/dhm25200_1**). (D) Graphic representation of the computer-generated straight line that is contoured to the terrain between birthplace (UHZ) and 3 weather stations. These lines are used to calculate the topographic quotient q.

The heat index describes how hot the weather is felt subjectively in °C. Because it depends on the thermal neutral zone of the concerned organism, it was calculated for temperatures above 15 °C, which corresponds to the upper limit of the thermal neutral zone of cows [20].

For the assessment of climatic effects on gestation length, weather data was attributed to individual births. A set of weather stations closest to each birthplace were preselected based on the geographical coordinates of the center of each postal code area (Fig. 1B). The geographical data was provided by the Swiss geographic information center, Swisstopo (www.swisstopo.admin.ch). Because some stations did not have measurements for all parameters, the stations were preselected for each parameter independently. If no measurement was available within a 10-km radius, the parameter was omitted in the data set. In a second step, local topographical features between birthplace and weather station (Fig. 1C) were considered, and a topography quotient q was computed as the ratio of the length of the profile line between the birthplace (Fig. 1D, e.g. UZH) and the weather stations (Fig. 1D, e.g. Fluntern/ Kloten/ Affoltern) and the air-line distance between the two locations according to:

$$q = \frac{\sum \sqrt{\Delta x_i^2 + \Delta y_i^2 + \Delta z_i^2}}{\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}}, \tag{4}$$

with the latitude x, the longitude y, the elevation z, and the map resolution $\Delta x_i = \Delta y_i = 200m$. A q-value close to 1 indicates little elevation between the two locations and thus the weather is likely to be similar. Consequently, of the preselected weather stations, these with a q closest to 1 were selected.

Extreme geographic regions of weather stations and birthplaces higher than 1,800 m above sea level were excluded, because in these regions changes in weather variables could differ between proximate locations.

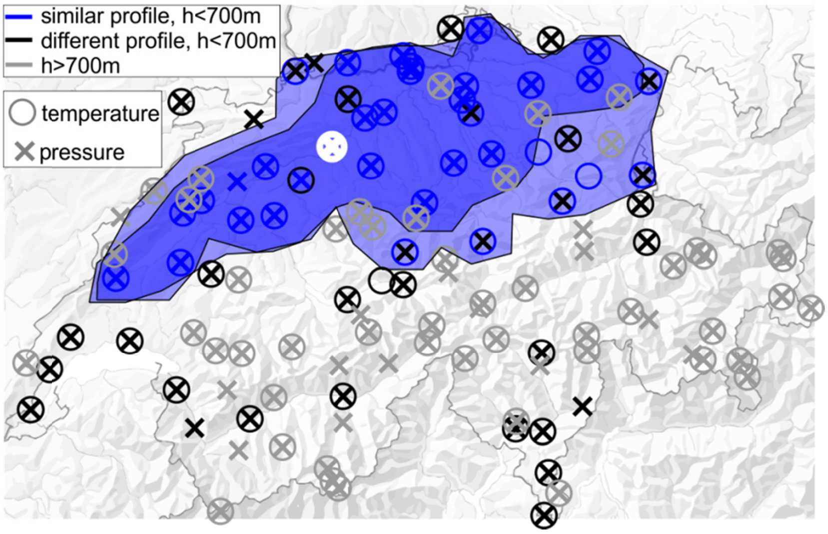

Fig 2. Area with same weather conditions. Swiss weather stations with similar temperature (blue circles) and barometric pressure profiles (blue crosses), stations with dissimilar profiles (black crosses and circles) and stations higher than 700 m above sea level (grey circles and crosses). The region with a homogeneous temperature profile is shown in light blue and the region that also has a homogeneous barometric pressure profile is shown in dark blue. The weather station that is most representative of the area shown in dark blue is marked with a white circle and cross.

For the assessment of climatic effects on the daily birth rate, area(s) with homogeneous weather conditions needed to be identified, which would count sufficient births to allow statistical analysis. According to MeteoSchweiz (personal communication Felix Blumer) barometric pressure and temperature are the variables with the most profound effects on weather conditions. In order to identify the weather station representing the largest area of Switzerland, the temperature and barometric pressure profiles of all stations below 700 m above sea level were compared for the entire three-year study period, using

$$\overline{\Delta p}_{k,m} = \frac{\sum_{i=1}^{N_d} \left(p_{k|i} - \bar{p}_k\right) - \left(p_{m|i} - \bar{p}_m\right)}{N_d}, \qquad \overline{\Delta T}_{k,m} = \frac{\sum_{i=1}^{N_d} \left(T_{k|i} - \bar{T}_k\right) - \left(T_{m|i} - \bar{T}_m\right)}{N_d}, \tag{5}$$

with the mean barometric pressure $\bar{p}_k$ at station *k*, pressure $p_{k|i}$ at station *k* on day *i* for all days $i \in [1, N_d]$ from January 1, 2008 to December 31, 2010, corresponding to a total of $N_d = 1827$ days, and the analogous variables for temperature T. Two weather stations *k* and *m* were considered similar if the mean differences of the daily temperature and the daily barometric pressure were smaller than $\Delta T_{\max} = 1\ °C$ and $\Delta p_{\max} = 0.7\ hPa$, respectively. For each weather station ($k \in [1, N_s], N_s = 336$) the number of similar stations (n_k) was computed according to

$$n_k = \sum_{m=1}^{N_s} \left(\overline{\Delta p}_{k,m} < \Delta p_{\max}\right). \tag{6}$$

To study the effect of climate on the birth rate, the population under investigation needed to be subject to similar weather conditions. The weather station that represente the largest number of others was located in Wynau (white circle and cross in Fig. 2). Thus for the analysis of climatic effects on the birth rate, all births that occurred within a 10 km radius of all stations similar to Wynau were considered (dark blue in Fig. 2). In the years 2008 to 2010, there were 859,027 (41% of all subjects) cattle births available for analysis in this area. The resulting region is in agreement with the observation of MeteoSchweiz that the weather conditions are largely homogeneous on the Swiss Plateau because this flat area is bordered by the Alps in the south (personal communication Felix Blumer).

2.3 Lunar data

Lunar data for the years 2008 to 2010 were retrieved from the NASA website (http://eclipse.gsfc.nasa.gov/phase/phase2001gmt.html). For each birth the time elapsed since the previous new moon was computed. For simplicity, the value was rounded down to the next full day. Due to the average lunar cycle of 29.53 days, fewer animals were attributed 29 days than in the other groups. Thus these were omitted for calculations in order to work with equally sized groups.

2.4 Statistical analysis

The program JMP9 (SAS Institute Inc., Cary NC, USA) and STATA 12 (Stata Corp., College Station, TX, USA) were used for statistical analysis. All analyses were done using multiple linear regression models with a stepwise backward elimination. The level of significance was set to $p < 0.01$.

While RGL and SIBR are normally distributed, the daily differences between maximal and minimal value of pressure (Δp), temperature (ΔT), and relative humidity ($\Delta\varphi$) generally are not. Hence, various transformations were tested to identify the one that generated the best linearity. Square root, inverse square root and common logarithm transformations were used to normalize the input data. However, for simplicity, this is not detailed in the following formalism.

2.4.1 Gestation length

To assess factors affecting gestation length (RGL), the following model was built:

$$RGL \sim \sum_j \Delta p_j + \Delta T_j + \Delta\varphi_j + \Delta p_j \Delta T_j + \Delta p_j \Delta\varphi_j + \Delta T_j \Delta p_j + \Delta p_j \Delta T_j \Delta\varphi_j \tag{7}$$

with the residual of gestation length *RGL*, the difference of maximal and minimal barometric pressure Δp_j, the difference of maximal and minimal temperature ΔT_j, and the difference of maximal and minimal relative humidity $\Delta\varphi_j$ on day *j* before parturition ($j \in [0,-1,-3,-5,-10]$, with $j = 0$ corresponding to the day of birth). To capture all possible cofactor dependencies, calculations were performed with all interaction terms such as e.g. $\Delta p_j \Delta T_j$. The days 0,-1,-3,-5 and -10 were taken into account to also capture the influence of the weather conditions in the time before parturition.

Furthermore, a linear regression model was used to identify correlations between RGL and the heat index (HI) at days *j* before parturition ($j \in [0,-1,-3,-5,-10]$):

$$RGL \sim \sum_j \Delta HI_j \tag{8}$$

The effect of thunderstorms on RGL was tested by a linear regression model including the occurrence of thunderstorms (TS) at days *j* before parturition ($j \in [0,-1,-3,-5,-10]$):

$$RGL \sim \sum_j TS_j \tag{9}$$

2.4.2 Daily birth rate

To assess factors affecting the daily birth rate on the Swiss Plateau, the following model was built for the season independent birth rate (SIBR):

$$SIBR \sim \sum_j \Delta p_j + \Delta T_j + \Delta\varphi_j + \Delta p_j \Delta T_j + \Delta p_j \Delta\varphi_j + \Delta T_j \Delta p_j + \Delta p_j \Delta T_j \Delta\varphi_j, \tag{10}$$

with the difference of maximal and minimal barometric pressure Δp_j , the difference of maximal and minimal temperature ΔT_j , and the difference of maximal and minimal relative humidity $\Delta\varphi_j$ on day *j* before parturition ($j \in [0,-1,-3,-5,-10]$). In analogy to the analysis of the RGL, the cofactor dependencies were included by accounting for all interaction terms such as e.g. $\Delta p_j \Delta T_j$. The days 0, -1, -3, -5 and -10 were taken into account to also capture the influence of the weather conditions in the time before parturition.

2.4.3 The lunar cycle

To quantify the effect of the lunar cycle on the onset of parturition, a chi-square test was performed, comparing the expected and the observed likelihood of being born on days 0 to 28 after a new moon. As the lunar cycle is not influenced by season, the unstandardized birth rate (BR) was used to analyze the difference between the observed BR on the 29 days of the lunar cycle and the expected BR using a chi-square test. Additionally, a one sample binomial test was used to test whether the BR of a single test day significantly differs from the expected BR. To make sure that seasonal changes do not mask the influence of the lunar cycle, the same calculations were also done for SIBR.

3 RESULTS

3.1 Aminals and farms

The 2,091,159 animals used in the study can be attributed to 26 breeds on 41,565 farms. The resulting number of birth per herd over the three years observation period was 50 ± 42 (maximum 994 births, minimum 1 birth of the same herd).

Table 1. Breeds of beef and dairy cattle used in this study.

Breed	***count***
Angus	41,358
Aubrac	3,819
Blonde d'Aquitaine	4,326
Braunvieh	481,430
Charolais	10,645
Dexter	3,195
Eringer	19,017
Evolène	1,018
Galloway	5,787
Grauvieh	8,158
Hereford	2,335
Highland-Cattle	5,808
Hinterwälder	2,725
Holstein	235,156
Jersey	10,530
Cross-bred	429,680
Limousin	115,004
Montbéliard	27,046
Normande	3,259
Piemontese	3,305
Red Holstein	25,946
Rotfleckvieh	564,671
Salers	1,757
Simmental	75,821
Swiss Fleckvieh	7,650
Belgian Blue	1,713

3.2 Gestation length

The multiple linear regression model revealed a significant correlation between RGL and Δp on the day of birth and the days d_{-0}, d_{-5} and d_{-10}, ΔT on d_{-0}, and $\Delta\varphi$ on d_{-3}, d_{-5} and d_{-10} (Tab. 2). All interaction terms showed no significant correlations between RGL and fluctuations in barometric pressure, temperature, and relative humidity at the day of birth and the days 0, -1, -3, -5, -10 before parturition.

Table 2. Significant results of the multiple linear regression with RGL and Δp, ΔT, $\Delta\varphi$ on the days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} after stepwise backward elimination.

RGL	Coefficient	SEM	t	P > t	95 % Conf. Interval	
Δp (d_0)	0.1041	0.0141	7.38	0.000	0.0764	0.1317
Δp (d_{-5})	0.0602	0.0140	4.31	0.000	0.0328	0.0876
Δp (d_{-10})	0.0413	0.0139	2.97	0.003	0.0140	0.0685
ΔT (d_0)	-0.0554	0.0146	-3.80	0.000	-0.0839	-0.0268
$\Delta\varphi$ (d_{-3})	-0.0020	0.0007	-2.95	0.003	-0.0034	-0.0007
$\Delta\varphi$ (d_{-5})	-0.0023	0.0007	-3.34	0.001	-0.0037	-0.0010
$\Delta\varphi$ (d_{-10})	-0.0042	0.0007	-6.19	0.000	-0.0055	-0.0029
intercept	0.0405	0.0559	0.72	0.469	-0.0691	0.1501

The regression analysis between RGL and HI revealed a significant decrease in RGL with increasing HI on days d_{-3}, d_{-5} and d_{-10} (Tab. 3).

Table 3. Significant results of the multiple linear regression with RGL and HI on the days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} after stepwise backward elimination.

RGL	Coefficient	SEM	t	P > t	95 % Conf. Interval	
HI (d_{-3})	-0.0081	0.0036	-2.26	0.024	-0.0151	-0.0011
HI (d_{-5})	-0.0084	0.0031	-2.68	0.007	-0.0146	-0.0023
HI (d_{-10})	-0.0364	0.0023	-16.11	0.000	-0.0408	-0.0319
intercept	0.3757	0.0139	27.1	0.000	0.3485	0.4029

The regression analysis between RGL and thunderstorms revealed a significant decrease in RGL with the occurrence of a thunderstorm on days $d_{0,}$ $d_{-1,}$ d_{-3}, d_{-5} and d_{-10} (Tab. 4).

Table 4. Significant results of the multiple linear regression with RGL and thunderstorms on the days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} after stepwise backward elimination.

RGL	Coefficient	SEM	t	P > t	95 % Conf. Interval	
TS (d_0)	-0.4398	0.0565	-7.78	0.000	-0.5506	-0.3291
TS (d_{-1})	-0.4036	0.0568	-7.11	0.000	-0.5149	-0.2922
TS (d_{-3})	-0.4653	0.0557	-8.35	0.000	-0.5744	-0.3561
TS (d_{-5})	-0.3731	0.0562	-6.64	0.000	-0.4831	-0.2630
TS (d_{-10})	-0.5332	0.0552	-9.65	0.000	-0.6415	-0.4250
intercept	-0.0060	0.0103	-0.58	0.560	-0.0261	0.0142

3.3 Birth rate

The analysis revealed a significant correlation between the SIBR and Δp on d_{-3} and ΔT on d_{-1} (Tab. 5). Furthermore, all interaction terms showed no significant correlations between SIBR and fluctuations in barometric pressure, temperature, and relative humidity at the day of birth and the days 0, -1, -3, -5, -10 before parturition.

Table 5. Significant results of the multiple linear regression with SIBR and Δp, ΔT, $\Delta \varphi$ on days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} after stepwise backward elimination.

SIBR	Coefficient	SEM	t	P>t	95 % Conf. Interval	
Δp (d_{-3})	7.2004	2.6646	2.70	0.007	1.9722	12.4289
ΔT (d_{-1})	6.4376	2.0629	3.12	0.002	2.3900	10.4852
intercept	753.8923	7.9472	94.86	0.000	738.2988	769.4857

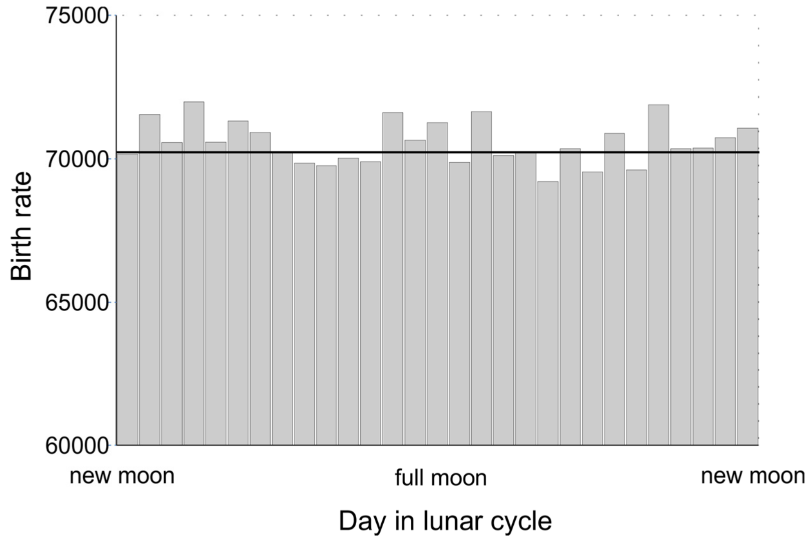

Fig. 3. Lunar cycle. Birthrate during the 29-day lunar cycle. The horizontal line marks the expected number of 70,662 births per day.

3.4 The lunar cycle

The expected likelihood of a birth occurring on one of the 29 lunar days was 0.03448, which differed significantly from the observed likelihood in the effective birth rate (BR) as well as in standardized number of births (SIBR, both $p < 0.0001$). Compared with an expected number of births per day of 70,562 (BR), the maximum numbers occurred on day 4 after a new moon with 71,987 and the minimum number occurred on day 20 with 69,211 births per day. A period with a significantly lower BR between day 9 and 12 was followed by a period of a higher BR between day 13 and 15 (Fig. 3).

4 DISCUSSION

Many factors can influence the onset of birth. Most of the known factors are local and affect a single herd or group of animals. It is to be expected that at herd level the management is a major contributing factor. The effect of management could be neglected in the present study, because the herd size is very small in Switzerland and data of the births all over the country was used. The mean number of births per herd over the 3 years observation period was 50 ± 42, reflecting the small influence of single herds in relation to the total data set with 2,091,159 observed births. Little is known about the effect of global factors like weather and lunar cycle in mammals, although it is frequently stated anecdotally.

4.1 Influence of barometric pressure, temperature and relative humidity

The influence of weather on the onset of parturition was investigated using two different surrogates: normalized gestation length (RGL) and birth rate (SIBR).

Table 6: Summary of effects of weather fluctuations on SIBR and GRL

	Δp	ΔT	$\Delta \varphi$
Residuals of Gestation Length (RGL)	↑	↓	↓
Season Independent Birth Rate (SIBR)	↑	↑	×

As general tendency summarized in Tab. 6, it could be observed that pressure fluctuation (∆p) increase the RGL and SIBR while temperature fluctuations (∆T) lead to lower RGL but higher SIBR. Humidity (∆φ) shows only a significant decreasing influence on RGL but does not affect the SIBR. The interpretation of these results is puzzling: Although according to meteorology pressure and temperature fluctuation are tightly coupled weather parameters and hence should have similar effects on gestation length (personal communication, Felix Blumer MeteoSchweiz), they are inversely related to RGL. In contrast, the results for SIBR look more consistent. However, for a statistical significance level of 5% (instead of 1%) temperature fluctuation three days before parturition is negatively related to the SIBR. This contradiction is due to the complex non-linear interactions between the three climate parameters resulting in random significances when they are all included in a generalized linear model.

The lack of climate dependence presented here complies with several other studies. A survey involving 672 cows from a single herd, in which onset of parturition was associated with a significant fall in barometric pressure during the preceding 3 days. The mean pressure fell by 0.9 hPa but rose again by 0.5 hPa during the last day before parturition [7]. No association between barometric pressure and onset of parturition was detected in two studies involving human births occurring in two different hospitals [10,11], but in another, 19 % more births occurred on days when the barometric pressure was below the average of the preceding 8 years compared with days with average or increased barometric pressure [8]. In the same study, significantly greater barometric pressure fluctuations occurred on days with 2 or more births than on days with one or no births. Similarly, more births occurred within 24 hours after a fall in barometric pressure than within 24 hours before a fall in pressure [9]. All these studies assumed barometric pressure to be the predominant factor, which stands in agreement with the meteorological viewpoint that temperature and humidity represent only co-factors (personal communication, Felix Blumer MeteoSchweiz). The impact of barometric pressure on living organism has been repeatedly shown. In human medicine, barometric pressure and other weather conditions were observed to influence migraine and rheumatic pain. Frequency of migraine pain was significantly greater when the barometric pressure fell by more than 5 hPa on the following day [21]. Women with osteoarthritis of the hands had higher pain on days of rising barometric pressure than on days of falling or constant pressure [22].

Laboratory rats and guinea pigs had more frequent signs of pain at low barometric pressure than at high pressure after iatrogenic ligation of the 5th lumbar spinal nerve [23]. However, these pressure-related differences disappeared after destruction of the inner ear. The authors hypothesized that a pressure gradient between the atmosphere and the inner ear activates vestibular nuclei, which transmit signals to the hypothalamus, the part of the brain involved in pain processing. In the rat, there is morphological evidence of the existence of a pathway from the vestibular nuclei of the inner ear to the hypothalamus [24]. Consequentially, an influence on the birth process seems possible. It is conceivable that barometric pressure-related nervous stimuli reaching the hypothalamus affect the prepartum period and onset of parturition because hypothalamic hormones are involved in initiation of parturition [1].

4.2 Influence of heat index

Because heat index (HI) is a proxy for the subjectively felt temperature rather than the physical measurement, it is more reliable to assess biological effects. It is established as a stressor of cattle [25]. The regression model indicates that at a high HI at the days before parturition leads to a shorter RGL. However, although statistically significant, the effect is marginal and hence of practical relevance. In contrast, a similar, but much larger effect was identified in a study in humans. Gestation length of women dropped by up to 5 days when an extreme HI occurred on the day before birth [26]. Those authors explained this phenomenon with observations made in sheep and cattle. Sheep experimentally heat-stressed by exposure to a temperature of 48 °C for 75 min had a 60 % increase in oxytocin concentration in blood [17]. In-vitro culture of endometrium from pregnant cows had 20 times more $PGF_2α$ in the medium when incubated at 43 °C compared with an incubation temperature of about 39°C [27]. Oxytocin causes release of $PGF_2α$ *in vitro* in cultures of endometrial cells from pregnant cows as well as *in vivo* in pregnant cows [28]. The release of $PGF_2α$ is more pronounced in heat-stressed cell cultures and heat-stressed pregnant cows than in non-heat-stressed cell cultures and cows; however, the $PGF_2α$ release was less pronounced in pregnant cows than in open cows [28]. This led to the conclusion that the bovine fetus extenuates the oxytocin-induced release of $PGF_2α$ but that the extenuation is affected by heat stress [29].

Heat shock proteins 70 are up-regulated by heat stress and are believed to have an effect on onset of parturition in women [30]. These proteins have been associated with premature rupture of the membranes and premature delivery and thus with premature babies [31]. Heat shock proteins 70 were synthesized in increased amounts by heat-stressed cultures of endometrial cells from pregnant cows [27] but it is not known whether they have an effect on onset of parturition in this species. The association between heat index and onset of parturition could be a reason why the mean gestation length in the summer is shorter than in other seasons [2].

4.3 Influence of thunderstorms

We observed that the RGL was shortened about 0.4 days in case of a thunderstorm during any of the last few days before gestation. Again, this rather small reduction has no direct influence on the herd management. However, physiologically this observation may be explained as a result of increased cortisol concentration in the pregnant cows after thunderstorms. It is also known in dogs that some individuals react to thunderstorms with a massive increase (mean 207 %) in cortisol secretion [18]. It is conceivable that thunderstorms are also stressful to late-gestation cattle and thus elicit cortisol secretion, because in cattle stress also leads to an increased cortisol secretion [32,33]. Alternatively, thunderstorms are often attended with changes in barometric pressure, supporting the assumption that pressure is influencing birth.

4.4 Influence of lunar cycle

In agreement with studies in women [16], calvings in the present study were not evenly distributed across the lunar cycle with a lower BR before and a higher BR during full moon. To our knowledge, there have been no scientific explanations for the association between lunar cycle and onset of parturition. The gravitational force of the moon has been speculated to affect people as well as animals [16]. In another study, the effect of the light emitted by the moon on the melatonin level and reproductive cycle in women was investigated [34]; 28 % of the women examined started their menstrual cycle during a four-day period that was centered at the occurrence of a new moon, which differed significantly from the frequencies at other stages of the lunar cycle. Furthermore, at the start of their menstrual cycle, these women had significantly higher melatonin levels than at the time of ovulation. More research is needed to clarify the role of the lunar cycle in onset of parturition in cows.

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